Methodology for defining concealed earthquake sources -- application to the Puente Hills blind-thrust system, Los Angeles, California: Collaborative Research with University of Southern California, Harvard University, and the USGS – 01HQGR0035

Annual Project Summary - 2001

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Summary
This project examines Quaternary activity on the Puente Hills Blind-Thrust System (PHT) to assess earthquake hazards in southern California (Fig. 1). The PHT generated the 1987 Whittier Narrows (M_w 6) earthquake, and extends for 40 km along strike beneath northern Los Angeles. Structural analysis has defined the fault size, geometric segmentation, and Quaternary slip distribution. Seismic reflection profiles and boreholes acquired in our investigation have defined late Quaternary fault activity. Ongoing investigations seek to determine paleo-earthquake ages and magnitudes. Our results document a significant earthquake hazard beneath Los Angeles, while providing new methods to study blind faults elsewhere in the world.

High-Resolution Seismic Profiles
In 2001, we processed and interpreted high-resolution seismic reflection profiles (acquired in 2000) that image discrete folds in the shallow subsurface above two segments of the Puente Hills blind-thrust fault system (Pratt et el., 2001). The profiles demonstrate late Quaternary activity at the fault tip, precisely locate the axial surfaces of folds within the upper few tens of meters, and constrain fold geometry and kinematics. The Santa Fe Springs segment of the Puente Hills fault zone shows an upward-narrowing kink band with an active anticlinal axial surface, consistent with fault-bend folding above an active thrust ramp (Fig. 2). The Coyote Hills segment shows an active synclinal axial surface that coincides with the base of an 8-m-high topographic slope, consistent with tip-line folding or the presence of a backthrust (Fig. 3). The seismic profiles pinpoint targets for future geologic work designed to constrain slip rates and ages of past events on this important fault system.

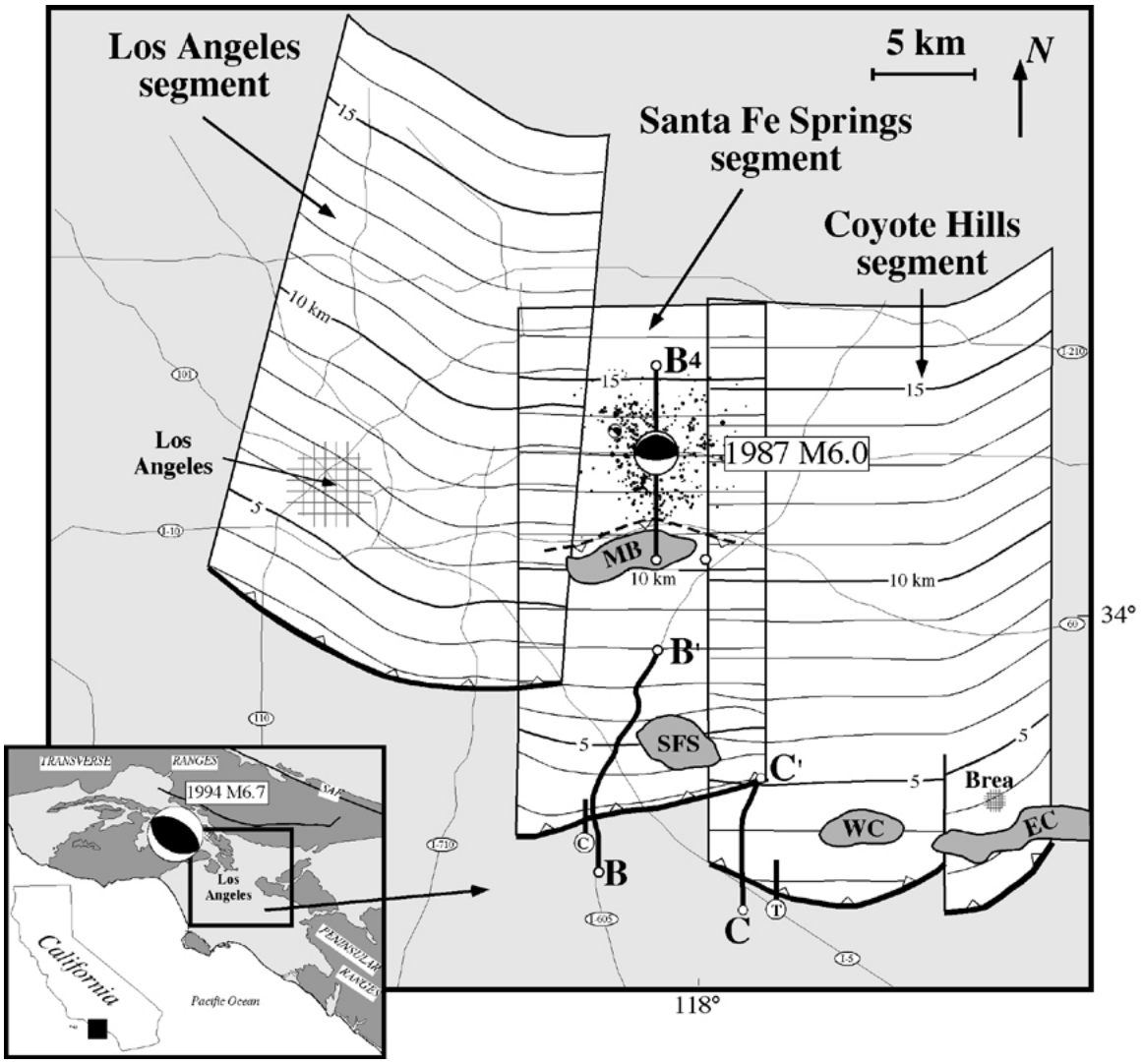

Figure 1: Structure contour map of segments of the Puente Hills blind thrust (PHT) showing the location of the 1987 Whittier Narrows (M_w 6) earthquake sequence (Hauksson and Jones, 1989; Shaw and Shearer, 1999). B-B', and C-C' mark the traces of industry seismic reflection profiles, and traces T (Trojan Way) and C (Carfax) correspond to the high-resolution seismic profiles, shown in Figures 2 and 3. The inset shows the location of the PHT and 1994 Northridge (M_w 6.7) earthquake. Oil fields: EC - Eastern Coyote; WC - Western Coyote; SFS - Santa Fe Springs; MB - Montebello. Major state and interstate highways are shown for reference.

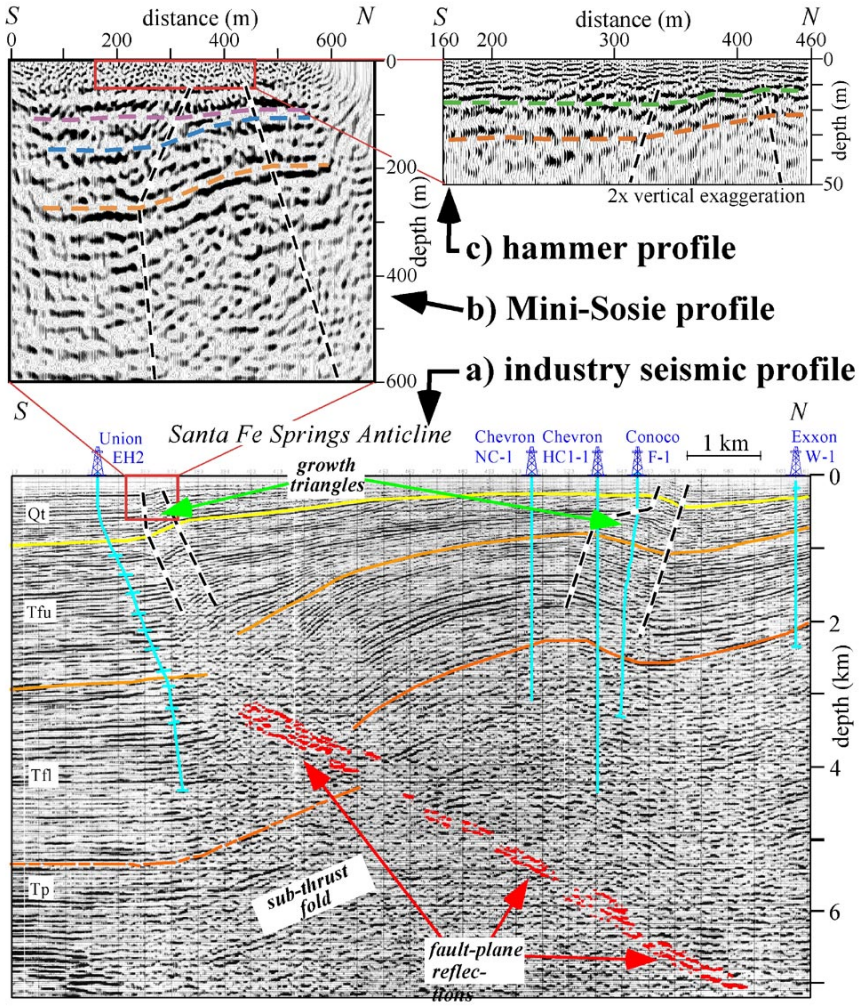

Figure 2: Carfax Avenue seismic reflection profiles (migrated). The profiles show discrete anticlinal and synclinal axial surfaces that define an upward-narrowing kink band at the forelimb of the Santa Fe Springs anticline above the Puente Hills fault zone. The industry and Mini-Sosie profiles are plotted with no vertical exaggeration, but the hammer profile has a 2x vertical exaggeration. The top of the industry profile is at sea level; the tops of the high-resolution profiles are at an elevation of about 27 m (the ground surface). The horizontal scale on the top of the Mini-Sosie and hammer profiles is the distance from the south end of the Mini-Sosie profile. Qt = Quaternary; Tfu = Pliocene upper Fernando Formation; Tfl = Pliocene lower Fernando Formation; Tp = Miocene Puente Formation. Industry data courtesy of Texaco, Inc. Section traces shown in Figure 1.

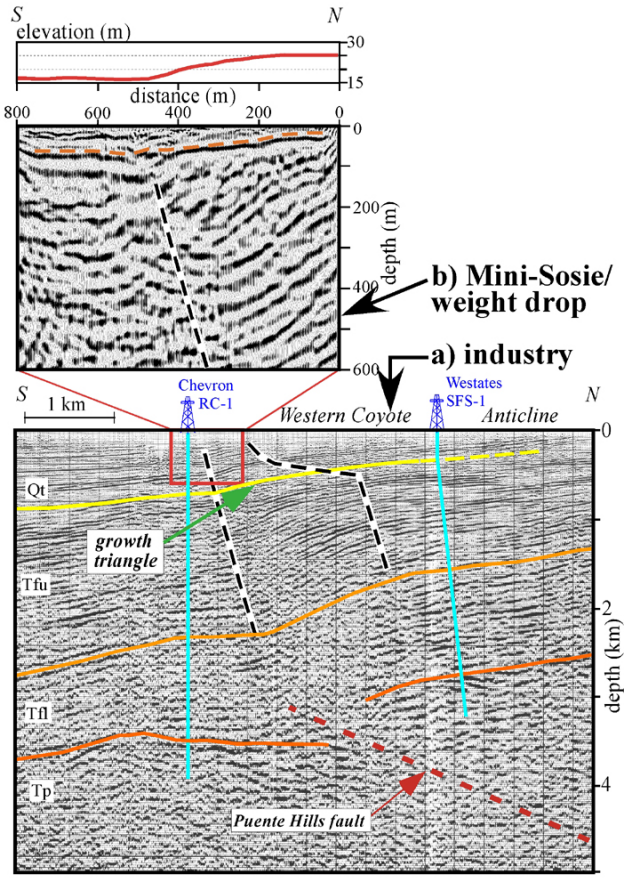

Figure 3: Seismic reflection profiles across the Coyote Hills segment of the Puente Hills thrust fault (migrated and plotted with no vertical exaggeration). The Mini-Sosie/weight drop profile was acquired along Trojan Way and the industry seismic profile was acquired along Valley View Avenue about 1.2 km to the west. The profiles show an upward-narrowing kink band whose synclinal axial surface corresponds with the base of a topographic slope. Qt = Quaternary; Tfu = Pliocene upper Fernando Formation; Tfl = Pliocene lower Fernando Formation; Tp = Miocene Puente Formation. Industry data courtesy of Texaco, Inc. Section traces shown in Figure 1.

The high-resolution seismic profiles demonstrate that folding above the PHT extends into the shallow sediments (<200 m) as discrete kink bands, consistent with the late Quaternary activity on the PHT implied by its projection to the hypocenter of the Whittier Narrows earthquake (Shaw and Shearer, 1999). The shallow fold scarps were not associated with observable surface deformation during the 1987 Whittier Narrows (M6.0) earthquake. Thus, their presence suggests that other earthquakes that involved discrete near-surface folding have occurred on the PHT in the past. As discussed by Shaw and Shearer (1999), these events may have occurred as individual ruptures of single fault segments ($\approx M_w$6.5-6.6) or as multi-segment ruptures ($\approx M_w$7.0).

Structural Modeling

We completed a 3-D structural model describing the geometry and Quaternary slip history of the Puente Hills blind-thrust system (PHT) using seismic reflection profiles, petroleum well data, and precisely located seismicity (Shaw et al., 2001). The PHT comprises three, north-dipping ramp segments that are separated by two major geometric segment boundaries (Fig. 1). Forelimb growth structures indicate that slip initiated on all three of the fault segments in the early Quaternary. Based on an analysis of these folds, we produce Quaternary slip profiles along each ramp segment. The defined slip patterns mimic the observed uplift and kink-band widths, and imply that slip is greatest near the center of each

segment and decreases toward the segment boundaries (Fig. 4). Overlapping slip zones at the segment boundaries imply that displacement is transferred from one ramp segment to the next in an *en echelon* manner, rather than by a discrete tear fault.

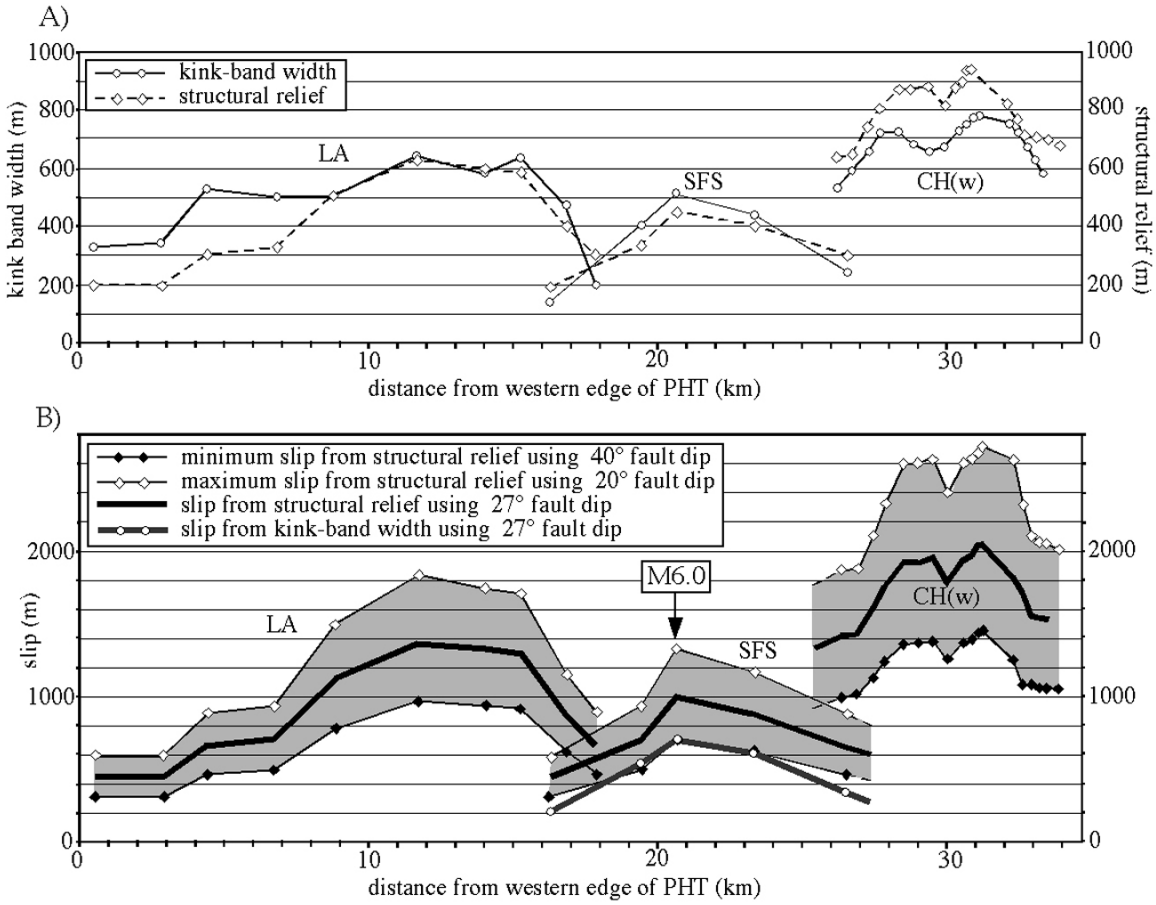

Figure 4: A) Plot of kink-band width and structural relief measured from depth converted seismic profiles across the forelimbs that overlie the PHT. B) Structural relief and kink-band width converted to slip using the methods described in Shaw et al., (2001), and preferred (27°) and conservative (20 to 40°) fault dip estimates.

Average Quaternary slip rates on the ramp segments range from 0.44 to 1.7 mm/yr, with preferred rates between 0.62 to 1.28 mm/yr. Using empirical relations among rupture area, magnitude, and coseimic displacement, we estimate the frequency of single (M_w 6.5 to 6.6) and multi-segment (M_w 7.1) rupture scenarios for the PHT to be 400 to 1320 years and 780 to 2,600 years, respectively.

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